MEMORANDUM:

DATE: February 9, 1999

SUBJECT: Stationary Combustion Turbines Emissions Database

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TO: Sims Roy
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The purpose of this memorandum is to document the activities conducted to develop and maintain the Stationary Combustion Turbines Emissions Database. This database will be used to support rulemaking decisions for the stationary combustion turbines NESHAP and NSPS efforts. The data gathering efforts, database development and refinements, and the data review process activities are described herein, as well as the format of the database and the development of emission factors using the database.

Data Gathering Efforts

The majority of source tests collected were conducted in the State of California as part of the AB2588 (Air Toxics "Hot Spots" Information Assessment Act of 1987) program. Complete copies of test reports for combustion turbines were gathered from all air districts in California and from previous EPA efforts, specifically STIRS (Source Test Information Retrieval System). Other states, including Washington, Texas, Pennsylvania, and New Jersey, and trade associations such as Western States Petroleum Association (WSPA) and Gas Research Institute (GRI), were also contacted for available source test reports.

A final data collection effort was made during the summer of 1998 to obtain additional test reports for hazardous air pollutants (HAPs) from combustion sources from the California Air Resources Board (CARB). This effort resulted in no new usable test reports for turbines. No additional emissions data collection efforts are currently planned.

Database Development and Refinements

The first version of the database, in Access 2.0, was released to the public (via the EPA ICCR TTN site) in June 1997. This release contained reports for hazardous air pollutants (HAPs) only. Version 2 of the database was released during January 1998, in both Access 2.0 and Access '97 formats. This version contained more HAP data than in version 1 and also contained criteria pollutant data. Version 3 of the database was released in September 1998 in Access 2.0 and contained additional test reports for HAPs and criteria pollutants received from GRI and a facility in California. The current version of the database is included with this memorandum (version 4, in Access '97). No new data has been added since version 3, but refinements and clarifications have been made to the database.

The current version of the database contains 238 tests, representing applications in industrial, pipeline, and utility sectors. The test dates of the source tests in the database range from 1988 to 1997. Some test reports contain HAP or criteria pollutant data only while other test reports contain data on both sets of pollutants. Seventy-two tests contain HAP data; the number with criteria pollutant data is 196. Many of the tests involved replicate sampling and analysis runs.

A list of references for the test reports included in the database is given in Appendix A. Test reports included in the database were numbered as follows: numbers from 1 to 99 were assigned to tests containing only hazardous air pollutants (HAPs), and numbers greater than 100 were allocated for tests with only criteria pollutants or with both HAPs and criteria pollutants. Exceptions are the reports numbered 10 and 15. These test reports contain both HAPs and criteria pollutant test results. They are numbered as HAPs-only type reports because criteria pollutant data were identified in these reports after the first version of the database was posted on the TTN. Test reports containing more than one turbine, multiple load conditions, different fuels, control device inlet and outlet samples, or more than three sampling runs were assigned the same initial number followed by an extension (for example, 1.1 or 1.1.1).

The test reports comprising the database include emissions data for turbines firing natural gas, distillate oil, digester gas, landfill gas, refinery gas, and field gas. The turbines tested ranged in size from 0.8 MW to 87 MW. Emissions were measured for various loads, ranging from 25% to 100% of full load. Some of the tested turbines were equipped with pollution control devices, including water or steam injection, lean pre-mix combustion design, and SCONOx.

Data Review Process

The extent to which operating parameters are included in the test reports varied. For consistency, test reports were reviewed according to a common set of acceptance criteria. These criteria are listed in Appendix B. When possible, pertinent information identified as missing from test reports was obtained by contacting the tested facilities.

Some test data were included in the database although the test report did not strictly qualify according to the acceptance criteria. Examples include reports with summary data only, reports containing confidential information, and reports with missing information that could not be obtained via facility contact. [Note: One test was flagged due to questionnable results. A complete description of the analysis of this report is included in Appendix C.] These reports were included in the database but are flagged by an "x" appearing after the ID number. They were included in order to have a more complete set of data for engineering analyses, although they should not be considered in analyses to determine numeric emission limits for standards.

At this point, the HAP emissions data have been the most critically scrutinized data in the emissions database. Further review of the criteria emissions data may reveal more test reports which should be flagged due to missing information or questionnable data.

Database format

The Stationary Combustion Turbines Emissions database consists of tables, queries, modules, and reports. Data extracted from the source test reports are entered into tables. Queries are used to collect selected data from the tables and to perform calculations using the data. This is done by calling specific functions within database modules. The result of the calculation is returned to the query. The reports draw on the queries and display raw data fields and calculated values. A brief description of each component of the database structure follows.

Tables

The database contains two master tables, a “Facilities” table and a “Test Data” table. The common field which links the two tables is the ID field which contains the Source Test Identification Number (these numbers correspond to those provided in Appendix A, Source Test References). The “Test Data” table was divided into three tables: “Test Data - HAPs,” containing all HAP data in the Test Data table, including the HAP data from reports with both HAP and criteria pollutant data; “Test Data - Criteria Pollutants,” containing all criteria pollutant data in the Test Data table, including criteria pollutant data from reports with both HAP and criteria pollutant data, and “Test Data - HAPs + Criteria,” containing only the data from tests with data for both HAPs and criteria pollutants. A list of data definitions identifying the various data fields in these tables is included as Appendix D. The data presented in the Facility and Test Data tables are “as reported” information. All calculations (corrected concentrations, emission rates, and emission factors) are performed within the database through the developed queries and modules and are displayed in the reports.

Queries

The queries in the database serve to organize and group data and to call functions to perform calculations on the data. There are two sets of queries. The first set contains the queries “qry_Emissions - Criteria Pollutants”, “qry_Emissions - HAPs”, and “qry_Emissions - HAPs + Criteria.” These queries contain the calls to functions within database modules which calculate the average reported run concentration, the average of the average reported run concentrations, the “corrected” run concentrations, and the calculated emission factors per individual test run and overall test average in lb/MMBtu, lb/MW, and lb/hr. The second set of queries includes the queries “Summary - Criteria Pollutants”, “Summary - HAPs”, and “Summary - HAPs + Criteria.” In these queries, the reported individual test run concentrations are corrected to 15% O_2 and the average of the corrected concentrations is computed.

Modules

Using raw test data (i.e., lab-reported pollutant concentrations and stack test parameters), calculations are performed to correct reported concentrations to 15% O_2 and to estimate emissions in lb/hr, lb/MW-hr and lb/MMBtu. Modules are small programs written in Visual Basic code that were built to perform the calculations. Each module contains functions. Calculations are performed within the module using parameters sent from the query when the function is called. The results of the calculation are returned to the query that called the module.

There are various modules in the emissions database that perform different tasks. A brief description of each of the modules used in the database follows:

Module AConc:	Computes the average concentration for the reported individual test run concentrations.
Module Convert:	Corrects the reported run concentrations to 15%O_2, inserts flags for non-detected concentrations, and calculates emission factors.
Module Correction:	Assigns the detection limit for a given run to run concentrations that are reported as non-detects.
Module NonDet:	Handles the criteria for the use of detection limits.
Module SigDig:	Performs the reduction of a calculated result to a given number of significant digits.

Reports

The report section contains several summaries of the calculated emissions data. Reports are included for individual test run concentrations as well as for average concentrations over all runs in the test. In the report section, a set of 6 different reports was built for each of the test data tables discussed above. These reports provide information about pollutant concentrations (corrected to 15% O_2) and emissions in units of lb/hr, lb/MMBtu, and lb/MW-hr. Individual sets of reports were also developed for test summaries and pollutant summaries. A listing of the reports included in the database is in Appendix E. In order to obtain the calculated emissions data, the appropriate report must be opened (when opening a report, all related queries and modules are run).

Many pollutants were not detected in some or all of the sampling runs conducted during a test. Individual run concentrations preceded by "<" in the reports indicate a non-detect concentration. In these cases, the full detection limit (DL) was substituted as the concentration for that run for calculation purposes. Detection limit values were not always provided and review of the lab report and additional calculations were necessary to determine the DL value. If the DL could not be calculated and the pollutant was not detected in all sampling runs, the pollutant was not entered into the database for that test. If more than one DL was determined for the same pollutant in a test, the highest DL value was used. A "<" appearing before an average concentration value indicates that at least one (but not all) of the individual run concentrations was a non-detect and the detection limit was averaged in as the concentration for that run. A "<<" preceding the average concentration denotes that *all* of the individual run concentrations were non-detects and that the detection limit was used as the concentration.

A more complete description of the treatment of non-detects and detection limits is provided in the memorandum attached as Appendix F. This memorandum also provides information on the calculations performed on the raw data and the default assumptions used in the calculations.

Emission Factors

Emission factors for turbines firing natural gas and distillate oil were developed using the emissions database. A description of the reports considered adequate for the emission factor assessment and the resultant emission factors are included as Appendices G and H (natural gas and distillate oil, respectively). These emission factors were calculated using the version of the database that was current in August, 1998. Minor differences may be present in emission factors calculated using the current version of the database.

Enclosure: Stationary Combustion Turbines Emissions Database, version 4

Appendix A
Source Test References

1. Sun, D.T. Metals, PAH, and Benzene Emissions Measurements - Cogen Exhaust Stack Response to AB2588 Toxic "Hot Spots" Act. Prepared by The Almega Corporation (Project # C6774) for ARCO Products, Carson, California. March 19, 1991.

2. Source Emission Test Report regarding Formaldehyde Emissions from the Agnews Cogeneration Facility, San Jose, California. Prepared by Best Environmental, Inc., San Leandro, California for Calpine, San Jose, California. October 2, 1992.

3. Bell. A.C. Emissions Inventory Testing at Long Beach Combustion Turbine No. 3 for Inclusion in Air Toxics Hot Spots Inventory required under AB2588. Prepared by Carnot, Tustin, California for Southern California Edison Company, Rosemead, California. May, 1989.

4. McDannel, M. D. Air Toxics Emissions Inventory Testing at Coolwater Generating Station Combustion Turbine No. 42 for Inclusion in Air Toxics Hot Spots Inventory required under AB2588. Prepared by Carnot, Tustin, California for Southern California Edison Company, Rosemead, California. May, 1990.

5. AB2588 Pooled Source Emission test Program. Prepared by Almega Corporation (Project # I6551) for Western States Petroleum Association, Glendale, California. July 9, 1990.

6. Source Test report AB2588 for Turbine #1 at Choachella Power Plant. Prepared by South Coast Environmental Company, La Verne, California for Imperial Irrigation District, Imperial, California. February 25, 1991.

7. Vacherot, R.J. Emissions Testing of a Gas-Fired Cogeneration Facility to Satisfy AB2588 Requirement. Prepared by Horizon Air Measurement Services, Newbury Park, California for Reese Chamber Systems Consultants, Inc., Somis, California. June 25, 1991.

8. Emission Measurements for Speciated PAH's and BTXE Compounds on Gas Fired Turbine and Steam Generator. Prepared by The Almega Corporation (Project # C6823) for Shell Western E & P, Bakersfield, California. August 1, 1991.

9. Source test report for the Texaco Heater Treater, the Mobil Steam Generator, and the SWEPI Gas Turbine in the San Joaquin Valley Unified Air Pollution District, California. Prepared by Radian Corporation for Western States Petroleum Association, Bakersfield, California. September, 1992.

10. State of California Air Resources Board, Engineering Evaluation Branch Monitoring and Laboratory Division, Project # C-88-014. Evaluation Test on a Natural Gas Fired Turbine

Cogeneration Facility, University Technical Services Inc., Taft, California. January 1989.

11. Emission Testing at Gilroy Energy Company. Prepared by Pape & Steiner Environmental Services, Bakersfield, California for Gilroy Energy Company, Gilroy, California. August, 1990.

12. Rooney, T. Emission Performance Testing of One Cogeneration Turbine at 32nd Street Naval Station, San Diego, California. Prepared by Western Environmental Services, Redondo Beach, California for Sithe Energies, U.S.A. Inc., San Diego, California. May 1991, revised November 1991.

13. Reel, T. Test Report: AB2588 Testing for South Bay Unit 2 and Kearny GT-1. Prepared by Carnot, Tustin, California for San Diego Gas & Electric Company, San Diego, California. October, 1991.

14. Report of Air Pollution Source Testing For California AB 2588 at the Kern River Cogen Company, Bakersfield, California. Prepared by Engineering-Science, Inc., Pasadena, California for Kern River Cogen Company, Bakersfield, California. March 28, 1990.

15. LeBarron, D. Determination of Polycyclic aromatic Hydrocarbons, Formaldehyde, CO, and NOX Emissions from Turbine Unit #2 at the Modesto Irrigation District McClure Road Generation Station, Modesto, California. Prepared by Ecoserve, Inc. Environmental Services, Pittsburgh, California for Modesto Irrigation District, Modesto California. November 28, 1990.

16. AB2588 Toxic Emission Testing LM2500 Cogen. Prepared by BTC Environmental, Inc., Ventura, California for Willamette Industries, Inc. Port Hueneme, California. October 21, 1991.

17. Pecaut, A.D. Emissions Testing From a Gas-Fired Cogeneration Facility To Determine Benzene Concentration. Prepared by Horizon Air Measurement Services, Inc. for Willamette Industries, Oxnard California. January 7, 1992.

18. McRae, G. Air Toxic Emissions testing of Natural Gas Fired Turbine at Sycamore Cogeneration Company, Bakersfield, California. Prepared by Engineering-Science, Inc. Bakersfield, California for Sycamore Cogeneration Company, Bakersfield, California. June 30, 1992.

19. Gas Turbine Emission Testing for McClure Generating Station. Prepared by Acurex Corporation, Mountain View, California for Modesto Irrigation District, Modesto, California. December 18, 1989.

20. AB2588 Testing at University Technical Services Petro-Lewis Cogeneration Plant, Taft, California. Prepared by Pape & Steiner Environmental Services, Bakersfield, California for

University Technical Services, San Diego, California. August, 1990.

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22. Schnitt, M.L. AB2588 Emission test Report, Procter & Gamble, Sacramento Cogeneration Facility. Prepared by Carnot, Tustin, California for Procter and Gamble Manufacturing Company, Sacramento, California. April, 1991.

23. Air Pollution Source Testing for California AB2588 on Heat Recovery Steam Generator at Chevron USA, Inc. Gaviota, California. Prepared by Engineering-Science, Pasadena, California for Chevron USA, Inc., Ventura, California. April 20, 1990.

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200. Test Report on Exhaust Emissions from Westinghouse B-8 Gas Turbine and Heat Recovery Boiler at the Baytowm Refinery, Boilerhouse 6. Prepared for EXXON Company, USA, 7, 1990.

201. Report of Oxides of Nitrogen Compliance Emission Determination of the Cogeneration System, Tastykake Company, Philadelphia, PN. Tested by BCM Engineers, Inc., October 1989

202. R. Burkeen, to M. Pratt. State Of New Jersey, Department Of Environmental Protection, Division Environmental Quality, Trenton, NJ. Memorandum: Nitrogen Oxide, Carbon Monoxide And Total Hydrocarbon Emission Testing For a Gas Turbine At Algonquin Gas Transmission Company, Hanover, NJ. November 13 and 14, 1990.

203. Engineering Testing at PGT Compressor Station 6, Unit A. Prepared by Carnot, Concord, California for Pacific Gas Transmission Company, San Francisco, California. November 14, 1994.

204. Test Report for the 1994 Initial Compliance and Monitor Certification Testing on the SoLoNOx Combustor (unit A) at PGT Compressor Station 6, Near Rosalia, Washington. Prepared by Carnot, Boulder, Colorado for Pacific Gas Transmission Company, San Francisco, California. October, 1994.

205. Compliance Source Test Report performed by Petro Chem Environmental Services, Inc., Bakersfield, California. Prepared for Pacific Gas Transmission Company, San Francisco, California. April 10, 1991

206. Test Report for the Relative Accuracy Test Audit at PGT Compressor Station 6, Unit A, Near Rosalia, Washington. Prepared by Carnot, Tustin, California for Pacific Gas Transmission Company, San Francisco, California. May, 1995.

207. Source Emission Evaluation for Northwest Pipeline Corporation for Roosevelt Compressor Station Solar Taurus T7000 Natural Gas Turbine, Klickitat County, Washington. Prepared by AmTest Air Quality, Inc. Preston, Washington. August, 1993.

208. Test Report for the Initial Compliance Testing at the PGT Compressor Station 7, Unit C, Near Starbuck, Washington. Prepared by Carnot, Concord, California for Pacific Gas Transmission Company, San Francisco, California. July, 1993.

209. Source Emission Evaluation for Northwest Pipeline Corporation for Willard Compressor Station Solar Turbines, Inc. “Centaur-H” T5500, Natural Gas Turbine, Willard, Washington. Prepared by AmTest Air Quality, Inc. Preston, Washington. September 27-28, 1994.

210. Source Test Report Four 75 Megawatt Gas Turbines Kern River Cogeneration Company, Bakersfield, California. Prepared by Engineering-Science for Submittal to San Joaquin Valley Unified Air Pollution Control District. March 9, 1993.

211. Emission Test Results at Compressor Station 6, Unit A, Near Rosalia, Washington. Prepared by Carnot, Tustin, California for Pacific Gas Transmission Company. Jan, 1991.

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220. Source Test Report Double C Limited, Bakersfield, California. Prepared by Petro Chem Environmental Services. March 1993.

221. Report of Annual Air Pollution Compliance Testing of a Gas Turbine Cogeneration Units. Prepared by Engineering-Science, Inc. for Kern County Air Pollution Control District. February 18, 1991.

222. Annual Compliance Test Chevron U.S.A.26C Cogeneration Plant Unit #'s 1,2,3,&4. Report #7777-0361. Prepared by Genesis Environmental Services Company. August 1992.

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224. Air Pollution Source Testing at Chalk Cliff Limited Cogeneration Facility, Maricopa, California. Prepared by Engineering-Science, Inc. for Submittal to San Joaquin Valley Unified Air Pollution Control District/Kern County APCD. January 1992.

225. Test Report on Exhaust Emissions from two Westinghouse Model W301-G Gas Turbines at the Refinery in Philadelphia, PN, Tested by Sun Reflining and Marketing Company, May 1991

226. Compliance Test Report #098-303 (Turbine) South Vandenburg Power Plant. Prepared by Petro Chem Environmental Services, Inc. December 1993.

227. Source Sampling Report for Measurement of NOx and CO Emissions, Combustion Turbine Units 11, 12, and 22, Philadelphia Electric Company. Report R-04-6314-000. Prepared by Gilbert/Commonwealth, Inc. August, 1991.

228. Combustion Turbine Emissions Test Report for Utilities of Springfield, MO. Prepared by Total Source Analysis, Inc. August , 1991.

229. Emission Testing at Coalinga Cogeneration Plant. Report PS-90-2284. Prepared by Steiner Environmental, Inc. for Shell Western Exploration & Production, Inc. October 1990.

230. Air Pollution Compliance Test for Two Turbines at Kern Front Limited Cogeneration Facility, Bakersfield, California. Prepared by Engineering-Science for Kern County Air Pollution Control District. March 1993.

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300. Measurement of Emissions, Total Energy Facility Gas Turbine at Joint Water Pollution Control Plant, Carson California. Prepared by Calscience Environmental Laboratories, Inc., Cypress, California for County Sanitation Districts of Los Angeles County, Whittier, California. August 17, 1992.

301. Measurement of Emissions, Total Energy Facility Gas Turbine No. 1, Digester Gas Inlet at Joint Water Pollution Control Plant, Carson California. Prepared by Calscience Environmental Laboratories, Inc., Stanton, California for County Sanitation Districts of Los Angeles County, Whittier, California. March 19, 1993.

302. Emission Tests on the Solar Turbine at Puente Hills Landfill. Prepared by Carnot, Tustin, California for Los Angeles County Sanitation District, Whitter, California. June, 1990.

303. Emission Tests on the Solar Turbine at Puente Hills Landfill, December 1990. Prepared by Carnot, Tustin, California for Los Angeles County Sanitation District, Whitter, California. February, 1991.

304. Emission Tests on the Solar Turbine at Puente Hills Landfill, August 1991. Prepared by Carnot, Tustin, California for Los Angeles County Sanitation District, Whitter, California. November, 1991.

305. Emission Tests on the Natco Turbine at Puente Hills Landfill, September 1993. Prepared by Carnot, Tustin, California for Los Angeles County Sanitation District, Whitter, California. November, 1993.

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312. Emission Tests on the Solar Turbine at Puente Hills Landfill, September 1993. Prepared by Carnot, Tustin, California for Los Angeles County Sanitation District, Whitter, California. November, 1993.

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Appendix B
HAPs and Criteria Pollutant Source Test Acceptance Criteria Checklist

	Source Test Report #____ Date__________	Source Test Report #____ Date__________
BASIC TURBINE INFORMATION		
Manufacturer	______________	______________
Model #	______________	______________
Rating (BHP or MW)	______________	______________
Operating Cycle (Simple, Regenerative, etc.)	______________	______________
FUEL DESCRIPTION		
Fuel Name(s)	______________	______________
Fuel Analysis Summary	______________	______________
Flowrate (or BTU/H, if available)	______________	______________
OPERATING CONDITIONS		
Load (during test)	______________	______________
Water or Steam Injection and/or Ammonia Mass Flowrate	______________	______________
Firing Temperature or Turbine Inlet Temperature	______________	______________
AMBIENT CONDITIONS		
Temperature	______________	______________
Relative Humidity	______________	______________
Barometric Pressure	______________	______________
Altitude	______________	______________
EXHAUST INFORMATION		
Temperature	______________	______________
Flowrate (F-Factor or Measured)	______________	______________
EMISSIONS TEST		
*Criteria Pollutants	______________	______________
HAPS	______________	______________
Oxygen or CO_2	______________	______________
Moisture	______________	______________
Averaging Time	______________	______________
METHODS USED		
CARB	______________	______________
EPA	______________	______________
Other ____________________	______________	______________
QUALITY CONTROL DOCUMENTATION		
Calibration of Instruments	______________	______________
Specialty Gases	______________	______________
CEMs	______________	______________
Dry Gas Meters	______________	______________
MISCELLANEOUS		
Limits of Detection Reporting	______________	______________
Supplemental Firing Details	______________	______________

*Attach separate sheet if necessary (ppb, ppm, lb per hr as measured and corrected to 15% O_2 or 12% CO_2, etc., dry).

Appendix C
Validity of Formaldehyde Emissions Data at Coolwater Unit 42

Two source tests were conducted on Southern California Edison's (SCE) Coolwater Station Unit 42, a water-injected Westinghouse 501B turbine. In the first set of tests (Test Report 4.1.1 and 4.1.2) conducted March 26-29, 1990, data were collected for a number of HAPs while the turbine was operated on fuel oil and then on natural gas. The emissions (lb/MMBtu) measured during fuel oil firing were consistent with emissions measured from other turbines. However, the formaldehyde emissions measured during natural gas firing were two orders of magnitude greater than the expected results. For this reason, the turbine was retested for formaldehyde only on October 31, 1990, while the unit was firing natural gas. This test is included in the database as test report #4.2. The formaldehyde emissions measured during this test were consistent with the formaldehyde emissions measured from other natural gas-fired turbines.

The test reports were reviewed by Alpha-Gamma to identify differences in turbine operating conditions or quality control issues that could help explain the high formaldehyde emission measurement in the first test. Based on this analysis, which is included as Attachment C-1, it was concluded that there was not sufficient information to exclude the high formaldehyde emission data collected in the first test.

Members of the Combustion Turbine Work Group (CTWG) of the ICCR later reviewed the SCE Coolwater source test report in detail. Based on their review, a number of questions arose about turbine load, sample handling, and QA/QC results from the natural gas-firing phase of the March 1990 test. A memo prepared by the CTWG on this review is included as Attachment C-2; specific questions and concerns are listed below:

- Sampling equipment did not meet the QA/QC requirements of EPA Method 3B;
- Based on O_2 and CO_2 measurements, it does not appear that the turbine was operated at constant load as was indicated in the report;
- Samples were not analyzed within the time period specified by CARB Method 430;
- Sample blanks indicated contamination; and
- Sampling rate was very low for the relatively high range gas meter used during the March 1990 test.

Due to these concerns, the March 1990 test while the turbine was firing natural gas (test report #4.1.2) has been marked with an "x" to indicate that it should not be used in developing emission factors for combustion turbines.

Attachment C-1

Alpha-Gamma Review of Test Report 4.1.2

MEMORANDUM

DATE: February 2, 1998

SUBJECT: Formaldehyde Results for Combustion Turbine No. 42 at the SCE Coolwater Generating Station

TO: Sims Roy

FROM: Dan Herndon, Alpha-Gamma Technologies, Inc.

Emission tests were conducted on combustion turbine No. 42 at SCE's Coolwater Generating Station on March 26-29, 1990 and on October 31, 1990. Analysis was conducted for a number of pollutants in the first test. The second test was conducted to reevaluate formaldehyde emissions only, since the formaldehyde emission results in the first test were "inconsistent with and significantly higher than results from other natural gas fired turbines." In the first test, data were collected while the turbine was firing two different fuels, natural gas and distillate fuel oil. In the second test, formaldehyde emissions were measured while the turbine was firing natural gas.

Table 1 summarizes the formaldehyde emissions and turbine operating data collected during the two tests. As seen in Table 1, the formaldehyde emissions measured during natural gas firing in the first test were significantly higher (>30 times higher) than during both fuel oil firing in the first test and natural gas firing in the second test. Alpha-Gamma reviewed the test reports to identify differences in turbine operating conditions or quality control issues that could help explain the high formaldehyde emission measurement in the first test. Based on this analysis, which is discussed below, we do not believe that there is sufficient information to exclude the high formaldehyde emission data collected in the first test.

According to the first test report, the turbine was operated at a load of 63 megawatts (MW) during both natural gas and fuel oil firing. During the second test (i.e., the formaldehyde retest), the turbine was operating at a 72 MW load while firing natural gas. During the first test, the percent oxygen (% O_2) in the turbine exhaust gas ranged from 16.1% to 17.1% while firing natural gas and was about 15.7% O_2 while firing distillate oil. The higher %O_2 suggests that the turbine may have been operating at a lower load during natural gas firing. However, the fuel use data appear to confirm that the turbine was operating at about the same load while firing natural gas and fuel oil during the first test. The heat loads calculated using fuel use data and fuel heating values are 866 MMBtu/hr and 871 MMBtu/hr for natural gas and fuel oil firing, respectively.

Table 1. Formaldehyde Emissions and Turbine Operating Conditions
Turbine No. 42 at the SCE Coolwater Generating Station
(Westinghouse PACE 520 Combined Cycle Turbine)

	Test 1		Test 2[a]
Parameter	Distillate Oil	Natural Gas	Natural Gas
Test Date	3/28/90	3/29/90	10/31/90
Formaldehyde Emissions[b]			
Pounds/Hour (lb/hr)	0.93	29.0	0.35
Pounds/Million BTUs (lb/MMBtu)	$1.02x10^{-3}$	$3.82x10^{-2}$	$3.44x10^{-4}$
Fuel Use[c]	103 gal/min	870,000 std ft^3/hr	960,000 std ft^3/hr
Heating Value[d]	141,000 Btu/gal	995 Btu/std ft^3	995 Btu/std ft^3
Load (Megawatts)[e]	63	63	72
Heat Input (MMBtu/hr)[f]	871	866	955
%O2 in Turbine Exhaust Gas[g]	15.7	16.1 and 17.1	15.5
Water Injection Rate (gal/min)[h]	41 - 51	69 - 81	82

Note: Data presented in Table 1 were obtained from the following report: "Air Toxics Emissions Inventory Testing at Coolwater Generating Station Combustion No. 42." The first version of this report was prepared in May 1990, and the second version was prepared in January 1991. Except where noted, data in Table 1 were obtained from the January 1991 version.

[a]Formaldehyde was the only pollutant measured in the second test.

[b]Table 4-3 of the May 1990 and January 1991 reports present the formaldehyde emissions data from the two tests.

[c]Appendix C.2 and C.3.

[d]Appendix C.7.

[e]Table 3-2.

[f]Calculated using fuel use and fuel heat value.

[g]Table 4-6 and Appendix C.3.

[h]Appendicies C.2 and C.3.

The 16.1 and 17.1%O2 measurements shown in Table 1 were taken during the stack velocity tests. Percent O_2 measurements were also taken during the first test using a portable meter. The 3.82 x 10^{-2} lb formaldehyde/MMBtu emission rate shown in Table 1 for natural gas firing during the first test was calculated based on the 17.1% O_2 measurement. The normalized formaldehyde emissions would decrease by about 20% to 3.03 x 10^{-2} lb/MMBtu if the 16.1% O_2 measurement was used in the calculation. The 16.1% O_2 measurement appears to be a more representative value based on the %O2 readings taken with the portable O_2 meter, which ranged from 15.5% to 16.5% O_2.

During the first test, while firing natural gas, the water injection rate ranged from 69 - 81 gallons per minute (gpm), but it was about 80 gpm during most of the time period when natural gas was being fired. The water injection rate during the second test was 82 gpm even though the turbine was firing about 10% more natural gas. However, criteria pollutant emissions were not measured during either test. Therefore, no carbon monoxide (CO) or nitrogen oxides (NOx) data are available to evaluate and compare combustion conditions in the two tests.

Alpha-Gamma contacted Kevin Crosby, an expert in source testing who was formerly with the company that conducted the emission tests, to discuss quality control issues with the first test. He pointed out that the formaldehyde concentrations in the blank samples collected during the first test were higher than concentrations in the spike analyses conducted by the laboratory. This comparison suggests that the blanks may have been contaminated by formaldehyde in the ambient air. If this was the case, the DNPH solution used in the sampling train could have also been contaminated and resulted in an artificially high formaldehyde emission measurement. However, the blank and spike sample analyses cannot confirm whether or not the DNPH solution may have been contaminated.

Mr. Crosby suggested the gas meter used during testing as another potential source of uncertainty in the test results. A relatively high-range dry gas meter was used during all of the tests. Because the gas sample volume collected during testing was in the low range for the meter being used, the accuracy of the sample volume measurement may have been reduced. The sample volumes were lowest during natural gas firing in the first test, so the potential for error was greatest during this phase of the first test. However, this potential source of error cannot be confirmed based only on information in the report.

Mr. Crosby concludes that, although there are some uncertainties, the results from the first test are consistent in quality with other tests conducted using CARB 430 as it existed in 1990. Based on our analysis of the test reports and the input provided by Mr. Crosby, we recommend that the formaldehyde results from the first test remain in the turbine emissions database.

A memorandum documenting Mr. Crosby's analysis is included in Attachment A. It should be noted that Mr. Crosby developed his heat input comments using emission summary sheets provided to him by Alpha-Gamma. He did not have access to the full test reports which contain data sheets identifying the specific fuel usage rates during the tests.

Attachment A to Attachment C-1

Memorandum

To: Brahim Richani, Alpha-Gamma
From: Kevin Crosby, Avogadro Group (formerly Northern Cal. Office of Carnot)
Subject: Formaldehyde results for 1990 testing by Carnot at SCE Coolwater

Brahim:

You and I discussed the results of tests done to measure emissions of formaldehyde from the gas turbine unit at SCE Coolwater. As I understand your situation, you wanted to qualify the data in question for inclusion in a database. Therefore, the data should represent emissions at full load on the unit. The results from the tests run while the turbine was fired on oil appear to be reasonably representative, while those from the operation on natural gas seem odd.

As we discussed on the phone, there are several reasons for considering the results to be non-representative. First of all, the oxygen concentration (approx. 17% vol. Dry) during the test runs on natural gas indicates that the turbine was operating at a reduced load. This conclusion is supported by calculation of the approximate MMBTU/hr value for the tests, which I did by dividing the average lb/hr results by the lb/MMBTU results for both fuels. For distillate oil, the heat input calculates to 912 MMBTU/hr, while for gas the result is 762 MMBTU/hr. The lower load condition is significant because the emissions of formaldehyde (and other products of incomplete combustion) are typically higher as the load on a turbine decreases.

We also discussed the uncertainty of the test results. The tests were conducted according to CARB Method 430 as it existed at the time. The uncertainty of the method was quite high then, and has been greatly reduced or improved in the more refined versions since then. The uncertainties for the 1990 natural gas results had several potential sources, which include:

- Contamination of the DNPH solution by exposure to formaldehyde in the ambient air (note that field blank analysis results were higher than spikes).
- Similar contamination of the recovery rinse water.
- Reduced accuracy in the metered gaseous sample volume due to use of a relatively high-range dry gas meter.

My conclusion in reviewing the results is that the uncertainty is high by today's standards, and the results at best represent emissions from the turbine operating at a reduced load condition. The results are typical in quality for tests conducted using CARB Method 430 as it existed in 1990. Please call me at (510) 680-4337 if you have any questions.

Attachment C-2

CTWG Review of Test Report 4.1.2

In the process of preparing the combustion turbine HAP emissions database, the Combustion Turbine Workgroup (CTWG) came across two HAP emission tests which were run conducted on Southern California Edison's (SCE) Coolwater Station Unit 42. The first set of tests, conducted March 26-29, 1990, included testing for a number of HAPs, including formaldehyde, while the combustion turbine, a water-injected Westinghouse 501B, was operating on natural gas and on fuel oil. The second test, conducted October 31, 1990, was for formaldehyde only while operating on natural gas.

The formaldehyde test results varied widely from one test to the other, prompting a considerable amount of speculation as to the validity of the data. While the second test yielded results similar in magnitude to other formaldehyde test on combustion turbines in the emission database, the first test showed formaldehyde approximately two orders of magnitude higher. The CTWG undertook a thorough study of both tests to determine the validity of each. After reviewing both test reports thoroughly, a number of questions arose about equipment condition, sample handling, and QA/QC in the March 1990 formaldehyde testing. It appears likely that the data from this test is invalid. A discussion of the problems noted follows.

The sampling equipment does not meet the QA/QC requirements of EPA Method 3B

EPA Method 3B specifies procedures and QA/QC requirements for the measurement of diluent gases from fossil fuel combustion processes, which can then be used to correct the measurements for stack conditions. EPA Method 3B specifies as a QA check that a fuel factor, F_o, be calculated and compared to an acceptable range of results. The fuel factor is calculated as follows:

$$F_o = \frac{20.9 - \%O_2}{\%CO_2}$$

, where $\%O_2$ is the measured flue gas oxygen content in percent by volume, and $\%CO_2$ is the measured flue gas carbon dioxide concentration in percent by volume.

The principle of this QA/QC check is that the ratio of CO_2 and O_2 in ambient air is known, and the ratio of the two substances resulting from the combustion of certain fossil fuels can be reliably calculated. If F_o is not within the expected range, it indicates a problem with the integrity of the sample train. According to the Table in 3.4.1.3 of EPA Appendix A, Method 3B, the range of acceptable Fo values for natural gas is 1.600 – 1.836.

For the March 1990 natural gas testing, the following O_2, CO_2, and F_o values were encountered:

Test Run	$\%O_2$	$\%CO_2$	F_o
1-PAH	16.10	3.31	1.45
2-PAH	16.16	3.07	1.54
3-PAH	15.67	3.33	1.57

Test Run	$\%O_2$	$\%CO_2$	F_o
4-Vel	16.10	2.36	2.03
5-Vel	17.10	1.87	2.03

Note that all of these values are outside of the acceptable range for Method 3B. The formaldehyde testing was performed between runs "4-Vel" and "5-Vel." Paragraph 3.4.1.3 of EPA Method 3B states that, "Calculated F_o values, beyond the acceptable ranges shown in this table, should be investigated before accepting the test results." The test report does not indicate that any investigation was performed to validate the data. Therefore, the data from the formaldehyde tests should be invalidated.

Knowledge of the Combustion Turbine process does not support tested values

In addition to the information presented above regarding potential sample train inaccuracies, knowledge of the combustion turbine process runs counter to the test data in the March 1990 test. Referring to the data highlighted above, the oxygen levels appeared to increase and the carbon dioxide to increase between Runs 4-Vel and 5-Vel. However, combustion turbines operate at a fixed fuel-air ratio at any given load, so the only explanation for such a significant shift in diluent gas levels is a change in combustion turbine load. However, Table 3-2 of the Test Report indicates that Unit 42 was run at a constant 62 MW load level. The testing data runs counter to established knowledge of the combustion turbine process, which should have prompted investigation. Again, no such investigation was performed, and the data should not be considered valid.

Samples were not analyzed within time period specified by CARB Method 430

CARB Method 430 specifies that laboratory analysis of field samples should be performed within 7 days of sampling. The sampling was performed on March 29, 1990, and the analysis was performed on April 24, 1990, or 26 days later. Allowing such a long time to elapse between sampling and analysis greatly increases the likelihood of sample degradation. This does not represent a minimal overrun of the suggested time between sampling and analysis, but instead represents a serious breach of test protocol. On this fact alone the sampling results for this test should be considered invalid.

Sample blanks indicate contamination

As already explained in a memorandum dated February 2, 1998 from Dan Herndon of Alpha-Gamma to Sims Roy of EPA, the formaldehyde blank samples showed formaldehyde concentrations (23.7 Fg average) which were higher than the spike analyses (10.5 Fg average) conducted by the laboratory. This suggests that the DNPH solution was contaminated. This was noted in the analytical report, as well. Aldehydes are quite prevalent in the atmosphere and it extremely easy to contaminate a sample by just exposing the DNPH solution to the atmosphere. Furthermore, the laboratory analyses were not corrected for the blank values. This casts further doubt on the validity of the samples and analysis.

Sampling rate in first test was too low

As also indicated in the February 1998 Herndon memo, the sampling rate in the March 1990 test was quite small (an average of 0.8 cubic feet per test), while the gas meter was a relatively high-range gas meter. This is an additional source of uncertainty.

Conclusion

The first and third items above are, in the opinion of the CTWG, sufficient on their own to invalidate the results of the March 1990 natural gas formaldehyde testing on Unit 42 at SCE's Coolwater Station. Furthermore, taken in combination with all of the other problems noted above, in particular, the apparent sample handling problems, there is a compelling case to invalidate this data. It would appear that this testing was fraught with sampling, sample handling, and analysis errors. The only conclusion that can reasonably be drawn is that the testing was flawed, and the results of the testing are insufficiently robust to use as a basis for rulemaking. Accordingly, the emissions data from the March 1990 natural gas formaldehyde testing at Coolwater Unit 42 should be identified in the CT Emissions Database as unsuitable for use in development of emission standards or factors.

Appendix D
Definitions of Database Fields

The "Facility" table contains the following fields:

ID	-	The Test Identification Number. The ID corresponds to the test reference number in Appendix A, Source Test References.
Facility Name	-	The name of the facility.
Location	-	The location of the test site.
Testing Company	-	The name of the company that conducted the test.
Date	-	The date the test was performed.
Tester	-	The name of the person that conducted the test.
Manufacturer	-	The name of the turbine manufacturer.
Model	-	The turbine model designation.
Load	-	The load at which the turbine is operated at during the test.
Rating	-	The rating of the turbine
Unit	-	The rating units.
Fuel Type	-	The fuel used for charging.
HV	-	The fuel heating value.
HVUnit	-	The units for the fuel heating value.
Hcap	-	The maximum heat output of the unit.
HCUnit	-	The maximum heat output units.
Fuel Factor	-	The developed F-factor in units of dscf/MMBtu.
Application	-	Any supplemental information, comments on turbine use, and any underlying assumptions.
Control Device	-	The type of device used to control emissions.

The "Test Data" table consists of the following fields:

ID	-	Test Identification Number.
Pollutant	-	The name of the hazardous air pollutant (HAP).
Method	-	The method used for sampling and quantification of pollutant.
Run 1 Conc R	-	The reported concentration for Run 1.
Run 2 Conc R	-	The reported concentration for Run 2.
Run 3 Conc R	-	The reported concentration for Run 3.
SD	-	The number of significant digits.
DL	-	The detection limit reported for the pollutant.
Avg Conc R	-	The average of the reported concentration for all runs.

C Unit	-	The units used for reported concentration
Run 1 O_2	-	The percent oxygen in exhaust measured in Run 1.
Run 2 O_2	-	The percent oxygen in exhaust measured in Run 2.
Run 3 O_2	-	The percent oxygen in exhaust measured in Run 3.
Blank Conc 1	-	The blank concentration for Run 1, when available.
Blank Conc 2	-	The blank concentration for Run 2, when available.
Blank Conc 3	-	The blank concentration for Run 3, when available.
Run 1 Rate	-	The pollutant emission rate reported for Run 1.
Run 2 Rate	-	The pollutant emission rate reported for Run 2.
Run 3 Rate	-	The pollutant emission rate reported for Run 3.
Avg Rate	-	The average pollutant emission rate for all runs.
R Unit	-	The units for the pollutant emission rate.
Run 1 Factor	-	The pollutant emission factor reported during Run 1.
Run 2 Factor	-	The pollutant emission factor reported during Run 2.
Run 3 Factor	-	The pollutant emission factor reported during Run 3.
Avg Factor	-	The average pollutant emission factor for all runs.
F Unit	-	The units for the pollutant emission factor.
Fuel Factor	-	The F-factor for the fuel used for firing (dscf/MMBtu).
Run 1 Gas Flowrate	-	The exhaust gas flowrate for Run 1.
Run 2 Gas Flowrate	-	The exhaust gas flowrate for Run 2.
Run 3 Gas Flowrate	-	The exhaust gas flowrate for Run 3.
Gas Flowrate Units	-	The units for the gas flowrate.
Fuel Heating Value	-	The heating value of the fuel.
Fuel HV Units	-	The units for the fuel heating value.
Standard Temp.	-	The standard temperature used for the emission calculations.
Standard Temp. Units	-	The units for the standard temperature.
Run 1 Fuel Flowrate	-	The fuel firing rate in Run 1.
Run 2 Fuel Flowrate	-	The fuel firing rate in Run 2.
Run 3 Fuel Flowrate	-	The fuel firing rate in Run 3.
Avg Fuel Flowrate	-	The average fuel firing rate for all runs.
Fuel Flowrate Units	-	The units for the fuel flowrate.
Run 1 % Moisture	-	The amount of moisture detected in the exhaust for Run 1.
Run 2 % Moisture	-	The amount of moisture detected in the exhaust for Run 2.
Run 3 % Moisture	-	The amount of moisture detected in the exhaust for Run 3.
Avg % Moisture	-	The average amount of moisture detected for all runs.
MW	-	The molecular weight of the pollutant.

Stack Temperature	-	The temperature of the stack.
Stack Temp units	-	The units of the stack temperature.
Comm	-	Any comments.

The following tables contain the same fields as the “Test Data” table:

- Test Data - Criteria Pollutants
- Test Data - HAPs
- Test Data - HAPs + Criteria

Appendix E
Reports Included in the Stationary Combustion Turbines Emissions Database

Report Title	Data Reported
"Criteria Pollutant Summary (lb/MW-hr)" "HAPs Pollutant Summary (lb/MW-hr)" "HAPs + Criteria Pollutant Summary (lb/MW-hr)	Pollutant, Fuel Type, ID, Turbine Description, individual test runs and average lb/MW-hr
"Criteria Pollutant Summary (lb/MMBtu)" "HAPs Pollutant Summary (lb/MMBtu)" "HAPs + Criteria Pollutant Summary (lb/MMBtu)"	Pollutant, Fuel Type, ID, Turbine Description, individual runs and average lb/MMBtu
"Criteria Pollutant Summary (lb/hr)" "HAPs Pollutant Summary (lb/hr)" "HAPs + Criteria Pollutant Summary (lb/hr)"	Pollutant, Fuel Type, ID, Turbine Description, individual runs and average lb/hr
"Criteria Pollutant Summary - Average conc @ 15% O_2" "HAPs Pollutant Summary - Average conc @ 15% O_2" "HAPs + Criteria Pollutant Summary - Average conc @ 15% O_2"	Fuel Type, Pollutant, ID, Method, DL, Concentration (at 15% O_2), Rating, Load
"Criteria Pollutant Summary/run - Concentrations @ 15% O_2" "HAPs Pollutant Summary/run - Concentrations @ 15% O_2" "HAPs + Criteria Pollutant Summary/run - Concentrations @ 15% O_2"	Fuel Type, Pollutant, ID, Method, DL, Corrected Concentration at 15% O_2 for each run, Concentration Units
"Facility Criteria Pollutants Summary (lb/MMBtu)" "Facility HAPs Pollutants Summary (lb/MMBtu)" "Facility HAPs + Criteria Pollutants Summary (lb/MMBtu)"	ID, Description, Manufacturer, Model, Testing Company, Date, Pollutant, Method, lb/MMBtu for each run and average

"HAPs Averages Max Avg"	Fuel, Pollutant, ID, Method, Uncorrected Concentration and Unit, maximum and average for lb/hr, lb/MMBtu, and lb/MW-hr

Appendix F

MEMORANDUM

DATE : March 6, 1998

SUBJECT : Documentation on the Combustion Turbines Emissions Database

TO : Combustion Turbines Project File

FROM : Ana Rosa Alvarez and Dan Herndon

This memorandum provides a short description of the development of the emissions database for turbines, including assumptions used in the underlying calculations.

Development of the Emissions Database

The emission test reports were first carefully reviewed and summarized. Facility name, location, testing company, date of testing, make and model of turbine, manufacturer rating (and units), load, fuel type, application and control device (for emissions) were entered in a table named "Facilities." Pollutant name, sampling method, concentrations and units, detection limits and units, % oxygen, fuel factors, exhaust gas flow rates, stack temperature, fuel heating value and flow rate, % humidity, standard temperature, and pollutant molecular weight were entered in a table named "Test Data." Emission rates (lb/hr) and emission factors (lb/MMBtu) were also entered in that table for comparison with the emissions calculated in the database using the pollutant concentrations for each test run.

Test reports included in the database were identified using the following scheme: numbers from 1 to 99 were assigned to tests containing only hazardous air pollutants (HAPs), and numbers greater than 100 were allocated for tests with only criteria pollutants or with both HAPs and criteria pollutants. Exceptions are the reports numbered 10 and 15. These test reports contain both HAPs and criteria pollutant test results. They are numbered as HAPs-only type reports because criteria pollutant data were identified in these reports after the first version of the database was posted on the TTN. Test reports containing more than one turbine, multiple load conditions, different fuels, control device inlet and outlet samples (criteria pollutant data only), or more than three sampling runs were assigned the same initial number followed by an extension (for example, 1.1 or 1.1.1).

Some of the test reports in the database include an “x” symbol at the end of the test report number (e.g., test report 8x). The “x” symbol indicates that the test report does not meet the acceptance criteria developed by the CTWG. The data from these test reports are included in the database for informational purposes only.

Construction of database reports (i.e., summaries of relevant data) required the complete separation of tests with HAPs-only data from tests with only criteria pollutant data and tests with both HAPs and criteria pollutant data. The “Test Data” table was consequently divided into three tables: “Test Data - HAPs,” containing all HAP data in the Test Data table; “Test Data - Criteria Pollutants,” containing all criteria pollutant data in the Test Data table, and “Test Data - HAPs + Criteria,” containing the tests that include data for both HAPs and criteria pollutants.

In the report section, a set of 6 different reports was built for each of the test data tables discussed above. These reports provide information about pollutant concentrations (corrected to 15% O_2) and emissions in units of lb/hr, lb/MMBtu, and lb/MW-hr. Individual sets of reports were also developed for test summaries and pollutant summaries.

Treatment of non-detected or non-reported concentrations

Many pollutants, especially HAPs, were not detected in some or all of the sampling runs collected during a test. In these cases, concentrations were entered in the database as “ND.” Although the test reports identified those pollutants not detected for a given testing run, the detection limit (DL) values were not always provided (i.e., ND was reported rather than a detection limit concentration). Often, review of the lab report and some additional calculations were necessary to determine the DL concentration. For example, in the case of formaldehyde, detection limits were usually given in micrograms or micrograms per milliliter in the lab report. Estimation of the DL in the same units as the test data (e.g., ppb) involved the use of the sample volume collected during the test and additional unit conversions (for example, micrograms/cubic meter to ppb).

Unfortunately, the DL could not always be found or calculated based on the laboratory report. Whenever a pollutant was not detected in all three runs and the DL could not be determined, the pollutant was removed from the database. This procedure was used for report ID #1 for benzene and chromium (VI). Also, due to the calculations discussed above, two or three different DLs (one per testing run) were determined for the same pollutant in some tests. The protocol followed in these cases was to take the highest DL value.

In some tests, only one or two runs were conducted, or runs were eliminated during test report preparation due to sampling problems encountered during the test. Missing runs were entered as NR (not reported) in the database. Other parameters missing from the test reports, such as exhaust gas flow rates, were also entered in the database as NR.

The acronym NA sometimes appears in the DL field. This acronym is used in those cases when a pollutant was measured above the detection limit in all of the testing runs but a detection limit value was not reported in the test report.

Equations

Using raw test data (i.e., lab-reported pollutant concentrations and stack test parameters), calculations were performed to estimate emissions in lb/hr, lb/MW-hr and lb/MMBtu. Modules, small programs written in Visual Basic code, were built to perform the calculations. There are various modules in the emissions database that perform different tasks, but only the main modules are described in this memorandum.

The equations used in the modules were taken from EPA sampling methods 19 and 20 in 40 CFR Part 60, Appendix A. For example, for the correction of the dry pollutant concentration to 15% O_2, Equation 20-4 from EPA method 20 is used:

$$C_{adj} = C_d * \frac{20.9 - 15}{20.9 - \%O_2}$$

where $\%O_2$ refers to the reported oxygen level during the testing and C_d to the pollutant dry concentration in ppb.

For the calculation of emission rates in lb/hr, lb/MW-hr, and lb/MMBtu, the following equations were used :

1. Pounds per hour:

When the concentration of pollutant is given in ppb :

$$M(lb/hr) = C_{ppb} * Q * 60 * \frac{MW}{T_{std} + 460} * 1.369x10^{-9}$$

where C_{ppb} is the dry concentration of pollutant in ppb; Q is the exhaust gas flow rate in dry standard cubic feet per minute; 60 is the conversion factor from minutes to hours; MW is the pollutant molecular weight (in lb/lb-mol); T_{std} is the standard temperature in degrees Fahrenheit used in the test report; 460 is the conversion factor from degrees Fahrenheit to degrees Rankine; and $1.369x10^{-9}$ is the conversion factor from ppb to pounds per cubic feet. The conversion factor from ppb to pounds per cubic feet was derived from 40 CFR, App. A, Meth. 20, page 1026.

When the concentration of a pollutant is given in units other than ppb or ppm, the equation is :

$$M(lb/hr) = C_p * Q * 60 * A$$

where C_p is the concentration of pollutant in micrograms per dry cubic feet (:g/dscf), micrograms per dry cubic meter (:g/dscm), grams per dry cubic feet (g/dscf) or grams per dry cubic meter (g/dscm). For particulate matter, concentrations are in grains per dry cubic feet (gr/dscf), grains per dry cubic meter (gr/dscm), micrograins per dry cubic feet (:gr/dscf) and micrograins per dry cubic meter (:gr/dscm). Q is the exhaust gas flow rate in dry standard cubic feet per minute; 60 is the conversion factor from minutes to hours; and A is a conversion factor from the given units to lb/dscf.

The values for A for the different units are:

1.1 For :g/dscf, A = 2.205×10^{-8}
1.2 For :g/dscm, A = 6.24×10^{-10}
1.3 For g/dscf and g/dscm, multiplying the values given for A in 1.1 and 1.2 by 1×10^{-6}, respectively
1.4 For :gr/dscf, A = 1.43×10^{-10}.
1.5 For :gr/dscm, A = 4.043×10^{-12}.
1.6 For gr/dscf and gr/dscm, multiplying 1.4 and 1.5 by 1×10^{-6}

2. Pounds per megawatt-hour:

The emission factor is calculated by dividing the emissions rate in lb/hr by the turbine rating during the test. The manufacturer rating and the test load are necessary data for this calculation. When load was not available, it was assumed to be 100%. The equation is :

$$M(lb/MW-hr) = \frac{M(lb/hr)}{\frac{R * L}{100}}$$

where M(lb/hr) is the emission rate in lb/hr; R is the manufacturer rating for the turbine in MW; and L is the turbine testing load in %.

3. Pounds per million Btu:

The equation is :

$$M(lb/MMBtu) = C_p * F * \frac{20.9}{20.9 - \%O_2} * B * \left(\frac{MW}{T_{std} + 460}\right)$$

where C_p is the dry concentration of pollutant in any of the units already described for the calculation of emission factors (1.1 - 1.6); F is the fuel factor in dry standard cubic feet per minute per million Btu; the fraction 20.9/(20.9-%O_2) is an oxygen correction factor; and B is the conversion factor corresponding to the units in which the pollutant concentration is reported (see the units described in 1.1 - 1.6). The fraction MW/(T_{std}+460) is a conversion factor used only when the pollutant concentration was provided in ppb.

When the fuel factor or standard temperature was not available, defaults were used. These defaults are discussed in next section.

A sample of the modules used for the calculations is provided in Attachment F-1.

Defaults and Assumptions

For the estimation of emission factors from the concentrations given in ppb, gaseous pollutants were assumed to have ideal gas behavior, so that the volume occupied by an ideal gas (22.4 liters/mol) could be used for calculation of a conversion factor.

Not all of the reports contained the necessary information required for the calculation of emission factors. Important parameters are concentrations, units, detection limits, oxygen levels, exhaust gas flow rates, fuel factors, standard temperatures and molecular weights. In most cases, fuel factors and standard temperatures were missing. In some cases, exhaust gas flow rates were not provided in the report. Lack of gas flow rates still allows for the calculation of emission factors in pounds per million Btu. Consequently, tests lacking exhaust gas flow rates were kept in the database, but the emissions in pound per hour are shown as NR.

For non-methane hydrocarbons (NMHC) and total hydrocarbons (THC), a molecular weight of 16 (as methane) was assumed. Test reports in the database indicated a molecular weight of 16 for THC and, in most cases, for NMHC. However, in some test reports, the molecular weight chosen to report emission factors for NMHC was the molecular weight of hexane.

Fields with NR for fuel factors and standard temperatures were filled with default values based on Table 19-1 in 40 CFR Part 60, Appendix A. A default standard temperature of 68°F was used. This standard temperature was selected because EPA sampling methods rely on this value.

As discussed earlier, some pollutants were not detected in one or more of the sampling runs conducted during a test. In these cases, the detection limit was used in the emission calculations. Reports generated in the emissions database use a “<” sign in front of the sampling run concentration, as well as the average concentration calculated for the three runs, to indicate when a pollutant was not detected in one or more of the runs. When a pollutant was not detected in all three runs, a “<<” sign is shown in front of the average concentration presented in the database reports. The DL value was used in calculating the average concentration when a pollutant was not detected in one or more of the runs.

Attachment F-1

Sample of modules used in the database

The modules shown here are the modules for the calculation of emission factors in pounds per million Btu (Module Convert) and the module that handles the criteria for the use of detection limits (Module NonDetect).

1. Module for the calculation of emission factors in pounds per million Btu

1.1 Declaring the function that will perform the calculations and return the result to the query. The parameters r, s, t, u, v, w, z refer to concentration units (r), fuel factor (s), molecular weight (t), standard temperature (u), % oxygen (v), concentration (w), and a parameter (z, set to three in the database) used to limit the number of significant digits (utilizing another module) in the result.

Function lbMMBtu (r, s, t, u, v, w, x, y, z)

1.2 Estimating the emission factor to return to the query that is calling this module. First the module identifies the units (r=ppb), then it makes sure that there are values in all necessary fields and finally performs the calculation. SigDig_ is calling another module that will perform the reduction of the result to a given number (z) of significant digits. Val calls for the numerical value of the field being processed.

```
If ((r = "ppb") And Not (s = "NR" Or t = "NR" Or v = "NR" Or w = "NR")) Then
    lbMMBtu = CStr(SigDig_((Val(s) * Val(t) * (.00000000137 / (Val(u) + 460)) *
                (20.9 / (20.9 - Val(v))) * Val(w)), z))

ElseIf ((r = "ug/dscm") And Not (s = "NR" Or v = "NR" Or w = "NR")) Then
    lbMMBtu = CStr(SigDig_((Val(s) * Val(w) * .0283 * .000000002204 *
   (20.9 / (20.9 - Val(v)))), z))

ElseIf ((r = "ug/dscf") And Not (s = "NR" Or v = "NR" Or w = "NR")) Then
    lbMMBtu = CStr(SigDig_((Val(s) * Val(w) * .000000002204 *
   (20.9 / (20.9 - Val(v)))), z))

ElseIf ((r = "gr/dscf") And Not (s = "NR" Or v = "NR" Or w = "NR")) Then
    lbMMBtu = CStr(SigDig_((Val(s) * Val(w) * (20.9 / (20.9 - Val(v))) / 7000), z))

ElseIf ((r = "ugr/dscm") And Not (s = "NR" Or v = "NR" Or w = "NR")) Then
    lbMMBtu = CStr(SigDig_((Val(s) * Val(w) * .0283 * (20.9 / (20.9 - Val(v))) *
```

```
                0.000001 / 7000), z))

ElseIf ((r = "gr/dscm") And Not (s = "NR" Or v = "NR" Or w = "NR")) Then
    lbMMBtu = CStr(SigDig_((Val(s) * Val(w) * .0283 * (20.9 / (20.9 - Val(v))) /
    7000), z))
```

1.3 In any other case (units not recognized or necessary parameters were not reported) the function is returned with the value "NR"

```
Else
    lbMMBtu = "NR"
    End If
End Function
```

2. Module Handling the use of non-detected values

2.1 Declaring the function that will return the values to the query. The parameters x and y refer respectively to concentration and detection limit.

```
Function Correction (x, y)
```

2.2 Identifying the concentration. If it is not reported, return the value "NR;" if it is not detected, take the value of the detection limit as the value for the concentration to be returned. Otherwise leave the value as it is.

```
If (x = "NR") Then
     Correction = "NR"
ElseIf
If  (x = "ND") Then
     Correction = y
Else
     Correction = x
End If

End Function
```

Appendix G

MEMORANDUM:

DATE: **August 12, 1998**

SUBJECT: **Emission Factors (lb/MMBtu) for Natural Gas Fired Turbines**

FROM: **Keri Leach, Alpha-Gamma Technologies**

TO: **Sims Roy**

The emission factors (lb/MMBtu) presented in Table 1 were calculated for natural gas-fired turbines from 23 source test reports in the emissions database. Emission factors from test reports that did not meet acceptance criteria established by the CTWG were not used in the calculations (4.1.2x, 8x, 10x, 29.1, 29.2, and 29.3). In addition, only test reports where the testing was conducted at high loads (greater than 80%) were included in the analysis. Test reports in which the load was not specified in the test report or could not be estimated from fuel use data were excluded. Test data for HAPs that were not detected in any of the sampling runs for a source test (i.e., where the concentration is ND in all test runs) were excluded. This exclusion was made on a pollutant basis such that we may have used data for a subset of the HAPs analyzed for in a particular source test.

The following test reports were used for the emission factor calculations: 2, 3.1, 4.2, 6.2, 7, 9, 11, 12.1, 13.1, 15.1, 17, 18, 22, 26, 27, 28, 313.1.1x, 313.2.1x, 314.1x, 315.1x, 316.1.1x, 316.2.1x, and 317.1x. Listed below are the source test reports that were excluded from the emission factor calculation with the reason for exclusion.

Test Report ID#	Reason for Exclusion
4.1.2x	Formaldehyde data point appears to be an outlier. Retest of the same turbine generated formaldehyde data more consistent with other formaldehyde data in the database.

8x	Report deemed inadequate by state and federal regulators according to telephone contact with the turbine operator.
10x	Missing load and fuel usage data.
29.1, 29.2, 29.3	Only summary data provided; no raw data sheets, laboratory results, etc.
16, 21, 313.1.2x, 313.2.2x, 314.2x, 314.3x, 314.4x, 315.2x, 316.1.2x, 316.2.2x, 317.2x	Testing occurred only at operating loads less than 80%.
23, 25	Load information not available.

Table G-1. HAP Emission Factors [Average, (Min-Max)] for Natural Gas-Fired Combustion Turbines

HAP	# tests	Average Emission Factor (lb/MMBtu)	Range (Min - Max)
Acetaldehyde	7	9.12E-05	(1.10E-05 - 3.50E-04)
Acrolein	2	5.49E-06	(4.90E-06 - 6.08E-06)
Benzene	11	1.03E-05	(1.34E-06 - 3.91E-05)
Ethylbenzene	1	4.10E-05	---
Formaldehyde	22	7.13E-04	(2.21E-06 - 5.61E-03)
Naphthalene	3	1.46E-06	(5.11E-07 - 3.31E-06)
PAH	4	2.23E-06	(1.44E-07 - 7.32E-06)
Toluene	7	1.42E-04	(1.05E-05 - 7.60E-04)
Xylene	5	4.59E-05	(1.19E-05 - 1.20E-04)

Appendix H

MEMORANDUM:

DATE: **October 9, 1998**

SUBJECT: **Emission Factors for Distillate Oil-Fired Turbines**

FROM: **Keri Leach, Alpha-Gamma Technologies**

TO: **Sims Roy**

The emission factors (lb/MMBtu) presented in Table 1 were calculated for distillate oil-fired turbines from 8 source test reports in the emissions database. Emission factors from test reports that did not meet acceptance criteria established by the CTWG were not used in the calculations. In addition, only test reports where the testing was conducted at high loads (greater than 80%) were included in the analysis. Test reports in which the load was not specified in the test report or could not be estimated from fuel use data were excluded. Test data for HAPs that were not detected in any of the sampling runs for a source test (i.e., where the concentration is ND in all three runs) were excluded. This exclusion was made on a pollutant basis such that we may have used data for a subset of the HAPs analyzed for in a particular source test.

The following test reports were used for the emission factor calculations: 12.2, 13.2, 15.2, 19, 223, 3.2, 4.1.1, and 6.1. Listed below are the source test reports that were excluded from the emission factor calculation with the reason for exclusion.

Test Report ID#	**Reason for Exclusion**
14x	Missing load and fuel usage data.
300.1, 300.3, 301.1	Testing occurred only at operating loads less than 80%.

Table H-1. HAP Emission Factors [Average, (Min-Max)] for Distillate Oil-Fired Combustion Turbines

HAP	# tests	Average Emission Factor (lb/MMBtu)	Range (Min - Max)[a]
Benzene	3	8.5E-05	(2.0E-05 - 1.25E-04)
Cadmium	1[b]	4.8E-06	---
Chromium	1[b,c]	1.08E-05	(1.02E-05 - 1.15E-05)
Formaldehyde	6	3.4E-04	(8.12E-05 - 1.01E-03)
Lead	1[b,c]	1.42E-05	(9.04E-06 - 1.93E-05)
Manganese	1[b]	7.89E-04	---
Mercury	1[b]	1.3E-06	---
Naphthalene	4	5.4E-05	(1.11E-05 - 1.53E-04)
PAH	6	3.4E-05	(8.4E-08 - 1.6E-04)

[a] For each test, an average emission factor was calculated for each HAP detected in one or more sampling runs. The range presented in this column represents the range in these average emission factors for all tests where the HAP was detected.

[b] Data from source test 6.1

[c] Two tests conducted on the same turbine using different test methods